Hyperspectral Optical Properties, Remote Sensing, and Underwater Visibility

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LONG-TERM GOALS

My overall goal is to advance our understanding of the utility of hyperspectral and high-spatial resolution remote-sensing imagery for estimating water-column optical properties, bathymetry, and mine-hunting optical systems' performance.

OBJECTIVES

Our major objectives are to investigate two problems related to the interpretation of hyperspectral remote-sensing imagery: 1) estimating underwater visibility and associated optical parameters from remote sensing data, and 2) quantifying the effects of resuspended sediments in optically shallow waters on remote sensing data and algorithms for predicting bottom depth and water optical properties.

APPROACH

Optically shallow waters are by nature highly dynamic environments that experience a variety of processes which alter their optical properties. For the application of hyperspectral remote sensing of optically shallow waters, it is important to understand the effects some of these processes have on the optical properties of the bottom boundary layer. Waves and tides, for example, resuspend sediments in varying degrees depending on topology, sediment characteristics, and the strength of the forcing mechanism. To a hyperspectral imager, the apparent reflectance of the bottom will change dramatically depending on these bottom boundary conditions. Although the interactions of waves and tides with bottom sediments have been studied and modeled, their effects on the bottom boundary-layer optical properties and hence on the remote-sensing reflectance has rarely, if ever, been systematically studied. As pointed out by Philpot [1989] and Maritorena et al. [1994], bathymetric mapping with passive multispectral imagery is a non-unique modeling problem. That is, for example, the same RSR can result from two different bottom depths if the bottom albedos differ accordingly. Similarly, an apparent change in the bottom albedo caused by a nepheloid layer will result in errors in bottom depth estimation from the RSR. However, these errors can be anticipated, and possibly corrected, if adequate information of resuspension events in the target area can be obtained and fed into an appropriate optical model.

On the CoBOP DRI we developed a new hyperspectral radiometer system called HydroRad that is designed to measure both bottom and surface spectral irradiance (and radiance) simultaneously. From these measurements the bottom spectral irradiance reflectance and surface remote-sensing reflectance

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **Hyperspectral Optical Properties, Remote Sensing, and Underwater Visibility**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Hydro-Optics, Biology, and Instrumentation Laboratories,,P.O. Box 859,,Moss Landing,,CA, 95039**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

are obtained. In addition to the time-series measurements of the bottom-boundary-layer optical properties, we are performing extensive IOP and AOP measurements of the water-column optical properties since these measurements will be needed to develop and test our shallow-water optical models. During ship deployments, we also collect water samples for analysis of particle size distributions, dry weight and composition. These measurements will be important for understanding and modeling the optical properties and optical effects of resuspended sediments and associated optically-active matter, which is still very poorly understood.

Optical modeling will consist of four major components: 1) developing optical-property models for resuspended sediments and associated optically-active matter, 2) forward numerical modeling for solving the radiative transfer equation, 3) developing empirically-based coupled hydrodynamic-optical models for bottom-boundary layer effects, and 4) developing semi-analytical models for remote sensing of optically shallow waters that includes the optical effects of the bottom boundary layer and suspended sediments in the water column. Modeling component (1) is straightforward and simply requires the appropriate data which we will collect on this program. Component (2) is easily achieved with Hydrolight, which the author has many years of experience using. Achieving component (3) will rely heavily on the quantity and quality of the mooring data and it is recognized that these models may be regional and require statistical tuning parameters. Modeling component (4) is also likely to be regional to some degree and its general applicability will no doubt depend on how comprehensive a data set we will be able to collect on HyCODE.

WORK COMPLETED

The original mooring schedule for the HOBI Labs optical packages called for us to begin installing instruments on the first Sea Diver cruise in February 2000. We completed preparations for this installation well ahead of schedule and thus took the opportunity to install instruments on the 30 m buoy in December 1999, two months ahead of schedule. During this December cruise we installed a HydroRad-4, *a*-βeta, *c*-βeta, and HS-2, including extended memory for data logging and external battery packs for long-term power requirements. By the time of the first Sea Diver cruise in February 2000, we had completed building a redundant set of instruments for the 30 m buoy mooring and developed a new and unique bottom-mounted mooring platform along with the optical instruments for this bottom mooring, namely a HydroRad-4, two *a*-βetas, two *c*-βetas, and a HS-2. Thus, by the time of the first Sea Diver cruise, when the installation of optical instruments on the WFS moorings was scheduled to be just beginning, we were already well underway with this effort.

Thus from February 2000 to August 2001, we maintained two optical moorings on a nearly continuous basis. This required building redundant sets of optical instruments for each mooring, so that on the two-month service cruises we could swap out instruments. We discovered that bio-fouling was a significant problem, even with service cruises every two months. We thus developed a copper shutter technology for the HydroRad and HydroScat-2 to protect the optics from fouling. A photograph of the HydroScat-2 with its copper shutter is shown in Figure 1. Figure 2 shows a similar photo of the HydroRad light collector's integrated copper shutter. These copper shutters cover the optics, preventing any growth or accumulation of dirt on the optics. During sampling the copper plate rotates out of the way of the optics. We found from our long-term deployments that these shutters would protect the optics and allow of accurate measurements for periods extending beyond three months.

In addition to the two month mooring service cruises, we participated in the hyperspectral overflight cruises, conducting extensive measurements or hyperspectral remote-sensing reflectance with the HydroRad fiber-optic radiometers.

RESULTS

To date the measurements we've been obtaining from the optical instruments installed at the 30 m buoy site and 10 m bottom site are of generally excellent quality and are providing much needed time-series optical data for the WFS site. The HydroRad hyperspectral radiometers in particular are providing surprisingly accurate measurements of spectral irradiance and radiance over long periods which are critical to remote sensing and radiative transfer studies on HyCODE. Currently we are completing the processing of these extensive datasets obtained from Dec. '99 to June '01, which is a substantial effort in itself. Preliminary analysis is already showing meaningful correlations with the Eckman transport predictions by Dr. Weisberg based on the current and wind data obtained from their moorings.

An important theoretical result was the development of a reformulation of the decomposition of the irradiance attenuation coefficient *K*. Although it is well known that the decomposition $K = K_w + K_p + K_y + K_d$ is theoretically incorrect, it is nonetheless often used in bio-optical models. I showed that this decomposition is not only mathematically incorrect, but scientifically meaningless. However, by redefining the individual terms as $K_w = a_w / \bar{\mu}$, $K_p = a_p / \bar{\mu}$, etc., where a_x is the absorption coefficient for constituent *x* and $\bar{\mu}$ is the average cosine of the *total* light field, the decomposition is then mathematically exact and the individual terms are scientifically meaningful [Maffione, 2001].

IMPACT/APPLICATIONS

Our long-term observations of optical properties in the west Florida shelf, continuously from moorings and synoptically from regular cruises, we further our understanding of optical variability in this type of coastal environment. This will allow us to develop and test predictive models of optical properties based on coupled circulation, productivity, and bio-optical models. Our parallel research on the relationship between underwater visibility and beam propagation parameters to remote-sensing reflectance will then allow us to estimate optical system performance based on remote-sensing imagery.

TRANSITIONS

The instruments and methods for long-term optical mooring that we have developed for this project are being used by HyCODE colleagues working at the LEO 15 site. They are also being used on a NOPP effort being conducted in the Monterey Bay area by the Monterey Bay Aquarium Research Institute, the Naval Postgraduate School, HOBI Labs, and others.

RELATED PROJECTS

I am working closely with investigators at USF (Carder, Weisberg, Walsh) to instrument an array of mooring sites in the west Florida shelf and collaborate on integrating the measurements into a coupled model being developed for this region. This project is also related to our research on light scattering funded by ONR (Investigation of Light Scattering by Ocean Waters).

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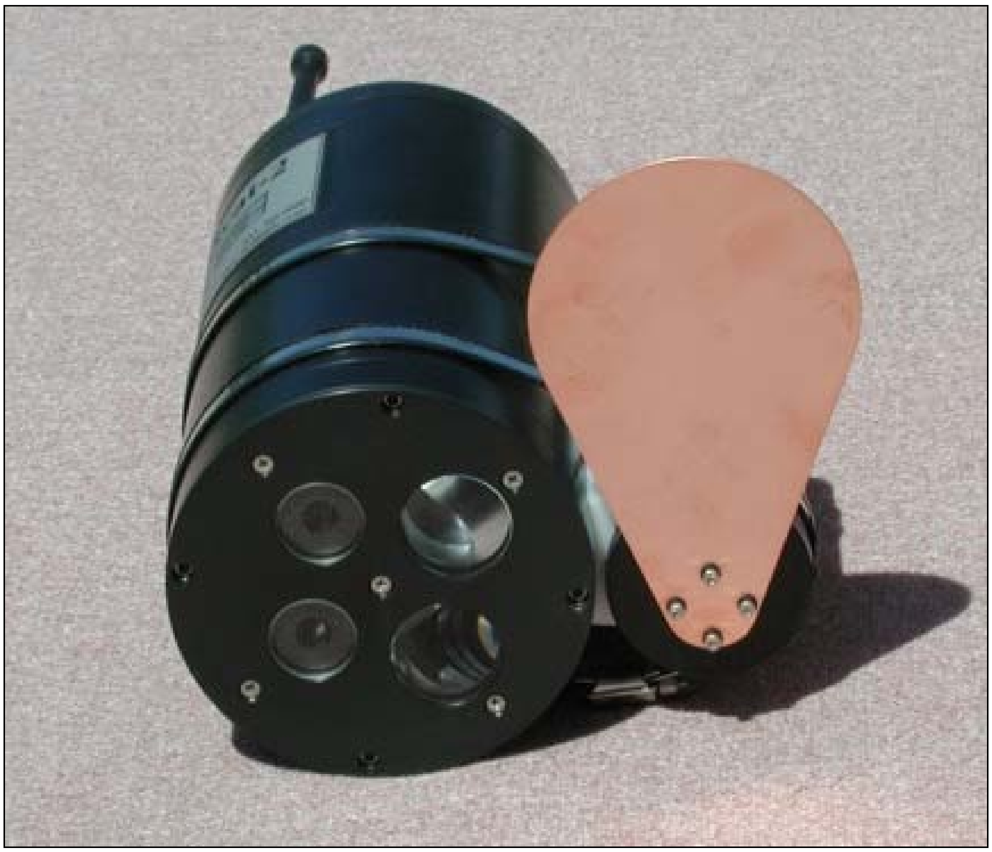

Figure 1. HydroScat-2 with new HydroShutter. The HydroShutter covers the optics of the HydroScat-2 with a copper plate to prevent bio-fouling. During sampling, the plate is rotated out of the way of the optics. Long-term mooring deployments have demonstrated that this technology keeps the optics free of fouling for over three months in highly fouling environments.

Figure 2. HydroRad fiber-optic light collector with new integrated HydroShutter. The HydroShutter covers the optics of the light collector with a copper plate to prevent bio-fouling. During sampling, the plate is rotated out of the way of the optics. Long-term mooring deployments have demonstrated that this technology keeps the optics free of fouling for over three months in highly fouling environments.